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REQUIREMENTS FOR FEDERAL EMP PROTECTION STANDARDS FOR TELECOMMUNICATIONS FACILITIES AND EQUIPMENT

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REQUIREMENTS FOR FEDERAL EMP PROTECTION STANDARDS FOR TELECOMMUNICATIONS FACILITIES AND EQUIPMENT

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FOREWORD

The Manager NCS, under a recent statement of national security telecommunications policy, is responsible for the development of standards and practices to improve the survivability and utility of Federal telecommunication resources during national emergencies. Accordingly the NCS has just completed a three phase study effort leading to the identification of specific EMP protection standards which should be developed to provide a reasonable degree of protection of government owned and leased telecommunication facilities against disabling dameage from EMP. Phase I and II results are depicted in NCS Technical Information Bulletin (TIB) 78-1 and 80-3 respectively. The Phase III results, identifying the categories of standards requiring development to decrease EMP vulnerabilities, are presented in this document. Comments concerning this TIB are welcomed, and should be addressed to:

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Executive Summary

This report identifies three interrelated standardization projects that can lead to the development of Federal EMP protection standards for application to telecommunication facilities and equipment. The purpose and scope of each project is described and provides the necessary focus for understanding the need for additional studies to acquire data for EMP standards.

These projects or programs, once complete, will provide the data for a complete specification of EMP protection requirements for those telecommunication facility and equipment design characteristics that contribute to disabling damage. The standardization study projects are separated into the three principal areas of (1) Facility Penetrator Protection and Isolation Standards, (2) Facility Shielding Protection Standards, and (3) Telecommunication Equipment EMP Test Specification Requirements Standards.

The importance of acquiring data for these standards as a group is stressed and an order of development suggested that will define each standards range of applicability at a practical engineering level. The data required for each area is defined and the uncertainties or unknowns are discussed in sufficient detail to support a recommended experimental and analytical program for resolving the known difficulties.

It is concluded that the most important standard to develop and verify is one that specifies the requirements for facility penetrator isolation. (Typical penetrators are signal cables and power lines that enter a facility.) This importance stems from the fact that penetrator effects are an order of magnitude greater than all other effects and by definition establish the bounds and requirements for the other two standards.

Recommendations are made to initiate a program that will provide the necessary data for the development of the three EMP protection standards.

1.0 Introduction

EMP Protection Standards applicable to telecommunication facilities and equipment are not available at the present time largely due to the immaturity of the EMP protection technology. Some uncertainty exists as to the effectiveness of the various protection techniques and the degree of protection effectiveness that should be allocated for each technique. Resolving the technical issues concerned with this technology are the first steps in the development and formulation of protection standards. This report identifies three specific and interrelated standardization projects that will provide essential engineering data such that a set of specifications and design requirements can be formulated and incorporated into EMP protection standards at some later date.

1.1 Background

EMP protection has been achieved in the past for command, control and communications facilities by a combination of techniques that include building shielding, the use of surge arrestors on power and signal lines (i.e., penetrators) and by shielding or filtering intrasite cables. In rare cases, equipment has been redesigned to increase the equipments ability to withstand the EMP transient coupled to it by facility penetrators or intrasite cabling. These procedures have been lengthy and expensive requiring engineering skills that are in short supply. The available information clearly indicates that the penetrators of a facility building (penetrators include power lines, waveguides, antennas and similar conductors) are the most significant contributors to the EMP energy within a facility that can damage telecommunications equipment. The second most significant contributors are the intrasite or interequipment cables within the facility. The equipment itself, of course, is usually no more than the passive recipient of the EMP energy and its ability to withstand a given amount of unwanted transient energy is a function of its design and its functional components.

A tradeoff exists between the costs of providing penetrator isolation, shielding of the building and its cables, and the equipments design capability to withstand the EMP transient. Independently, however, it is mandatory to standardize each of the three areas since each must have a unique protection effectiveness criteria. Some technical questions and uncertainties exist in each of these EMP protection areas regarding the effectiveness of known protection techniques, e.g. the reliability and safety of surge arrestors and filters on power and signal lines, and the confidence that can be placed in an equipment test specification derived from small test sample sizes. These questions among others, must be resolved before standards can be completed and applied in a convincing way.

The development of protection effectiveness criteria, the selection of candidate techniques, and their verification for each significant protection area requires a clear definition of standardization projects to eliminate these uncertainties. The main thrust of this report is to define these areas and suggest appropriate programs.

The emphasis of this report and in the proposed projects is to develop standards that will have the minimum impact on equipment design. In other words, the underlying motive is to obtain the maximum protection possible from the facility penetrator and shielding standards. The benefit from this approach is that most of the equipment now being manufactured or now in place would survive the EMP transient without design changes. Additionally, the final equipment test specification standard would be accepted by industry with less reluctance if the least strenuous test transient is adopted.

1.2 Report Organization

Three interrelated standardization areas are described which require additional data to resolve the knowledge voids that are now inhibiting the formulation of Federal EMP Protection Standards.

The most significant standard required is one that applies to Facility Penetration Isolation and is discussed first. Penetration isolation in this context means the isolation of the EMP energy collected by facility cables that penetrate the building. Examples of penetrators are power and signal cables and grounding arrangements. Candidate techniques are discussed for achieving the desired isolation effectiveness along with their known data voids that are presently limiting their application as protection standards.

The second area, shielding standards are discussed along with the shielding concepts unique to EMP. Data voids and factors limiting standards development are presented. This standard requires the development of technical specifications for the shielding of buildings/rooms/apertures and the techniques for the effective grounding of enclosures and cable shields.

The last standards discussion is that of equipment testing based on the formulation of a pass-fail criteria using specific EMP transient waveform amplitudes and energy levels. Two equipment categories are defined for specification development for the two separate conditions of shielded and unshielded facilities. The first category is for equipment connected to AC power mains while the second category contains all other equipment within the facility. Data deficiencies and requirements to complete these standards are defined.

The report conclusions and recommendations define a preliminary program plan to produce these federal EMP standards and acquire the necessary data.

2.1 Penetration Isolation Standards

Definition: Penetrators are any metallic object or conductor that enters the telecommunication facility and includes power cables, grounding conductors/rods, sewer lines, antennas and tower structures. Table 1 lists ten categories of penetrators.

2.1.1 Purpose and Scope

The purpose of penetration isolation is to reduce or isolate the EMP currents induced or coupled to penetrators to a level that will preclude damage to equipment connected directly to the penetrators. Additionally, the isolation must prevent the transfer of EMP currents on penetrators to nearby equipment cables such that the total sum of all penetrator EMP currents on any equipment cable is below a specified value. The standards will specify the required isolation or reduction, provide the construction and engineering details of the technique that will permit meeting the specifications, and lastly, define any necessary test or inspection criteria to verify the isolation/reduction effectiveness. The application of these standards to each of the penetrators in a facility building will be mandatory and are intended for incorporation at each telecommunication station in those networks that are critical to government communications.

2.1.2 Penetrator Isolation Techniques

Techniques for penetrator isolation must reduce EMP currents by at least 30 db to be considered effective and useful for standardization. The techniques available are limited to those that combine the use of metal entry plates with filters/surge arrestors. In practice the penetrators are routed to the entry plate which forms a boundary between the exterior and interior wiring of the facility building. The underlying principle is that the EMP energy from the exterior penetrators is diverted and rerouted when it intercepts the entry plate which achieves the objective of preventing the EMP energy from affecting the interior wiring. The effectiveness required of the various techniques at the maximum expected EMP currents depends on the electrical conditions present at the entry plate boundary. These conditions are altered by the degree of building shielding, the building structural grounding scheme, the presence of electrical filters/arrestors on the penetrator conductors, the use of unshielded conductors and the conductivity of the surrounding soil.

Three candidate techniques are listed in table 2 along with the principle unknowns that presently inhibit their development into standards. Each technique may require the addition of special EMP filters and arrestors at the entry panel to accomplish the desired 30 db of isolation. This complication is a result of the variation in electrical conditions at the entry plate boundary as mentioned above.

The first candidate technique listed in table 2 is a bench mark in that it is the most effective. This effectiveness is derived from the overall building shield that permits the EMP currents at the entry plate to be rerouted over a large metallic surface away from the buildings interior wiring. The shield also greatly reduces/eliminates the EMP currents induced in the penetrators located interior to the building. This secondary advantage reduces the dependency on special EMP penetrator filters/arrestors and eliminates the necessity for equipment shielding or intersite equipment cable shields. This ideal case is costly for retrofit situations but represents a viable standard for new construction. As such it requires full development as a standard.

The second candidate in table 2, the ground plane technique may be described as a degenerate case of the shielded building in that only one large metallic surface is available for rerouting the EMP currents. This plane also interacts with the equipment wiring by operating as a transmission line or relatively inefficient antenna configuration. These interactions are poorly understood and analytically intractable. Any variations in intrasite cabling configurations alter the EMP effects on the equipment and impose severe restrictions on any standards development for EMP equipment test specifications. Essentially, the equipment test criteria would be quite severe unless the intrasite cables were in shielded ducts. The application of this technique is plausible to retrofit and new construction and would employ the same penetrator installation criteria as that of the shielded building. In its most elementary form, the standard would have to specify that all equipment would be shielded and connected to the ground plane with all interconnecting cables carried in shielded ducts. Exceptions to this condition require experimentation and might include unshielded equipment, cables installed in floor wells, or shielded cables with connectors. Each exception permitted would affect the final value required for an EMP equipment test specification.

The last candidate is in widespread use today for antenna waveguide cable installations for microwave stations. Its extension to other types of penetrators is appealing and requires exploration on an experimental basis. In this configuration, the EMP currents are partly reflected by the entry plate and partly shunted to ground via the ground wires/rods connected to the entry plate. The addition of filters/arrestors also alter the EMP electrical characteristics of the penetrator/entry plate/ground rod combination which acts as a transmission line to the EMP pulse. Measuring the effectiveness of various combinations to determine an acceptable set is a difficult task but its low cost potential for retrofit situations makes it a viable and necessary candidate for standardization.

The final selection of the candidate(s) for standardization must be based on convincing experimental data as to their effectiveness and practical utility in suppressing the EMP characteristics/parameters listed in table 1 for each of the parameters. Additionally, the technique(s) selected should be biased towards the condition that imposes the least severe restraints on the subsequent development of an EMP test specification for equipment.

2.1.3 Relationship to Shielding and Equipment Test Specification Standards

Penetrator standards, EMP shielding standards and equipment EMP test specifications are a necessary and sufficient set for defining the EMP protection required to prevent disabling damage. The most important standard to develop first is that for the penetrators. This importance stems from the fact that EMP currents on penetrators exceed those on equipment cables and ground wires by a factor of 10 to 1000 depending on whether the penetrators are buried below ground or enter the facility above ground. In a practical sense, it is mandatory to reduce penetrator currents by at least a factor of 1000 or more to provide a rough equivalence between the two conditions. If this objective can be achieved, the shielding standards and the equipment test

specifications impose only a minimal design and cost impact. Secondly, if penetrator standards require the use of a shielded enclosure it is conceivable that an equipment EMP test specification may not be necessary.

A practical program for standards development therefore should determine the penetrator standards first, followed by shielding standards and ending with the development of the equipment EMP test criteria.

TABLE 1. PENETRATORS AND THEIR IMPORTANT EMP PARAMETERS

Penetrator	Expected EMP Energy	Expected Voltage Amplitude	Typical Impedances (ohms)	EMP Pulse Rate of rise	EMP Pulse Bandwidth (MHz)	EMP Pulse Waveshape
1. AC power	35 DB_J	100 KV	100	1 KV/ns	.1--10	xx
2. Signal cables	30 DB_J	50 KV	100	1 KV/ns	1--10	ds
3. Control cables	30 DB_J	50 KV	100	1 KV/ns	1--10	ds
4. Waveguide	30 DB_J	20 KV	20	1 KV/ns	1--10	ds
5. Antenna	50 DB_J	.7 MV	300	30 KV/ns	.01--100	xx
6. Water	5 DB_J	1 KV	20	10 V/ns	.01--10	xx
7. Sewage	5 DB_J	1 KV	20	10 V/ns	.01--10	xx
8. Fuel	5 DB_J	1 KV	20	10 V/ns	.01--10	xx
9. Air conditioning	5 DB_J	1 KV	20	10 V/ns	.01--10	xx
10. Grounding	30 DB_J	20 KV	20	1 KV/ns	.01--10	xx

xx = double exponential
ds = damped sinusoid
DB_J = decibels above one ujoule

Standardization Program for Penetrator Isolation

Candidate Standardization Techniques	
Technique	Unknowns
1. Entry panels with overall building shields. 2. Entry panels with building ground planes. 3. Entry panels with earth ground rods.	1. Unknown effectivensss for each of the three configurations at high EMP current densities as a function of bonding and grounding methods. 2. Specifications for protection devices/filters for each configuration is not available. 3. Imprecise knowledge of the hazards and performance of EMP protection devices when used with lightning protection devices under actual stress conditions.

Table 2

2.1.4 Technical Problems Limiting Standards Development

Table 1 lists the principle unknowns/uncertainties associated with the development of penetrator standards that must be resolved by analysis and experiments.

Each entry panel configuration, type of penetrator and protection/isolation technique listed must be tested at the maximum expected values of EMP listed in table 1. At the present time, only low level EMP test results are available and the predicted/postulated effects due to high level EMP are yet to be validated by a convincing experiment. These unknowns include the effects produced by the simultaneous operation of multiple EMP protection devices, the high voltage arcing possibilities at equipment or protection device terminals, the performance of EMP protection devices operating in conjunction with lightning protection devices, and the effects of grounding configurations/schemes on the reduction of EMP currents.

In the past protection devices have been bench tested on an individual basis with a particular equipment to validate protection performance. This is an acceptable procedure under some circumstances, but under actual conditions with perhaps 10 surge arrestors operating simultaneously the desired protection may be compromised due to an unwanted redistribution of the EMP currents because each arrestor offers a short circuit to the EMP and the number of possible paths for the EMP currents on facility wiring and grounds increase. Secondly, these short circuits placed on the wiring and cables when the arrestors operate cause high frequency ringing since the wiring will act as a shorted transmission line. Lastly the grouping of arrestors at an entry panel may create a situation where some arrestors do not operate due to the unbalances in ground impedance and the production variations in arrestor firing voltages.

The buildup of EMP currents on penetrators to magnitudes of 1000 amperes and more result in transient voltages exceeding 50,000 volts. Since arc-over takes place between a pair of conductors at about 30,000 volts for spacings of one inch we must expect this effect to be present at equipment terminals within a facility. In itself, arc-over is beneficial, since it acts as a surge arrestor which limits the EMP voltages to the voltage values at which the air gap between conductors breaks down. The undesirable result is that arc-overs can occur anywhere in the facility. For example, fuseholder fasteners can arc-over to their fuses which can result in power follow-through where the power supply via the fuse maintains the arc, eventually blowing the fuse and shutting down the equipment. The arc also creates the shorted transmission line condition which produces high frequency ringing effects plus multiple paths within the system wiring for the EMP currents. Overall, arc-over is undesired because its effects are unpredictable. The best course of action is to avoid arc-over by adopting a limitation on the maximum allowable EMP currents that is consistent with normally expected conductor spacings. One suggestion is that this maximum be 2.0 Ap-p on any of the interior facility wiring. This would limit voltages to about 100 volts and assure that arc-over would only occur for spacings of about .003 inches. In any event, an EMP isolation criteria must be established that considers the arc-over effects that are possible.

Another effect that must be considered in establishing a penetrator isolation criteria for EMP reduction is the performance and reliability of EMP protection devices that must operate in conjunction with any lightning protection devices installed on power or signal lines. The technical difficulty is that EMP surge arrestors are fast acting and cannot safely handle the lightning stroke energy which is normally much greater than that of EMP. In practice, the EMP device will operate on a lightning surge before the lightning arrestor does and possibly burn out or fail in the short circuit condition. The parallel operation of these two different and necessary devices requires engineering definition to prevent possible hazards and the assurance of prolonged EMP protection.

Grounding scheme specifications also play an important role in penetration isolation since the EMP currents are diverted or rerouted and reduced as a function of the number of the current paths available and the impedance of the paths. For example, if there are 10 equal impedance paths at the entry panel, the EMP current on any single path is only 1/10 of the total penetrator current. The ground paths also form complex coupling loops, transmission lines with resonant frequencies and scattering/reflecting surfaces that severely complicate the accurate prediction of EMP current reduction. Best estimates are that the various grounding schemes do not differ greatly from each other in their effectiveness in reducing the EMP currents, but the issue is still in doubt.

This brief outline of technical problems illustrates some but not all of the factors inhibiting the clear specification of a penetrator isolation requirement. Nevertheless these problems dictate that a standard include sections on grounding requirements, performance and reliability of protection devices, criteria for parallel operation with lightning devices, and the maximum acceptable penetration current feedthrough to the interior wiring. It is also clear, that an experimental program is necessary and that the program must include testing at the maximum EMP currents that are expected. High level testing will reveal the true effectiveness of the candidate techniques by forcing the operation of the protection devices and creating any non-linear effects caused by arc-overs and the short circuiting of the penetrators simultaneously.

2.2 Shielding Standards

Shielding standards are a necessary and integral part of the interrelated set of EMP protection standards for two reasons. First, many facilities already have room and building shields as well as penetrator cable and intra-site cable shields installed for other purposes such as radio frequency interference control. Therefore it is important to specify any additional shielding standards criteria that are unique to the EMP situation. Secondly, situations arise where building shielding for EMP can be the best solution to prevent disabling damage, e.g., a building without penetrators.

2.2.1 Purpose and Scope

The primary purpose of shielding is to prevent the pickup of EMP energy by the facility equipment to equipment wiring, and the interior extensions of the building penetrators. Shielding can take the form of overall shields, for buildings, rooms and equipment as well as the shielding of cables, individual wires or the enclosure of all cables within metal duct work. The scope of shielding concepts extend to those required to prevent EMP energy from entering apertures such as doors and windows. The topics involved in shielding are extensive and include material selection, grounding and bonding of shielded objects, and the definition of construction techniques for welding and bonding seams of enclosures.

This variety of shielding possibilities has been exploited over the years for various special purposes and a large data base exists for low level radio interference problem solutions. The extraction of this data for application to solve the EMP damage problem has been limited and uncorrelated to a set of specific equipment damage levels. This task is extremely difficult and time consuming. Therefore the initial efforts in standardization should be restricted to the specification of enclosure shielding, aperture shielding, and cable duct shielding.

This restriction recognizes that the normal shielding requirements for individual wires and cables placed on the racks used for radio frequency interference (RFI) control are insufficient to effectively protect against EMP damage because it has been proven almost impossible to verify by tests or analysis what changes are essential to assure EMP protection.

On the other hand, overall shielding is a tractable solution that permits analysis and testing, solves portions of the RFI problem and solves the EMP problem more conclusively than any other technique for both the new and retrofit situations. The standards for EMP protection that rely on cable or wire shielding alone plus their grounding techniques are out of reach at the present time in the technical sense. This is especially true for facilities and equipment designs that contain a large number of cables and wiring connected to equipment circuitry of unknown EMP damage endurance capability.

The necessity for the overall shielding standard is pervasive but its application to every facility is not mandatory. Basically it should be applied only to telecommunication networks that are critical to the government purposes since the cost of shielding can be quite large.

2.2.2 Shielding Techniques for Standards

The shielding techniques involved for buildings, rooms, cables, windows, doors or other apertures are well known and very little additional technical effort is necessary to formulate reasonable standards.

Table 3 lists three projects and the data that the standards should provide. The candidate criteria for shielded enclosure effectiveness for EMP protection has been selected such that the shield reduces the total EMP energy to 100 ujoules as measured in a standard 10 square meter loop terminated in 100 ohms when exposed to a 50,000 volt/meter field. The candidate criteria for apertures, cables, and cable ducts is the reduction of EMP energy in a pair of unshielded wires to 100 ujoules when the wire pair is a specified distance from the aperture or in the central portion of the cable duct while resting on the duct's metal surface. The exact value is not critical, nor is the measurement. What is critical is that the shielding effectiveness be referenced to a specific value of EMP energy as seen by a terminated set of wires that represent the equipment terminals.

Shielding in the EMP case provides one very significant advantage over other protection techniques: that is the increase of the very fast EMP rise time from values of 10 nanoseconds to about 1.0 microsecond. This advantage cannot be achieved by any other technique and provides considerable reductions in the EMP coupled peak voltages. For example, if the EMP voltage induced on an equipment cable is 1000 volt peak for the unshielded case, then the rise time increase due to shielding will reduce this voltage to 1.0 volt!

The metal shield acts as a giant filter affecting all cables and wires simultaneously. This is a huge protection simplification over any technique that seeks to restrict cable lengths, add filters to particular signal lines or shield a critical wire or two on sensitive circuits. This point is even more convincing when one considers the fact that every unshielded wire over 3 meters in length in a facility might require a protection device to prevent damage to sensitive equipment. This is an expensive task in the more complex facilities that house hundreds of cables and thousands of individual circuits.

Table 4 illustrates a sample and incomplete calculation for the 20db and 40db shield cases for two loop sizes. The table indicates that a 40db shield will provide sufficient isolation to protect an equipment that was designed to a 100 uj damage level even if the cable wiring encloses an area of 10 square meters. Figure 1 provides the equations for this calculation.

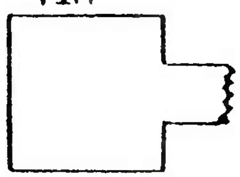
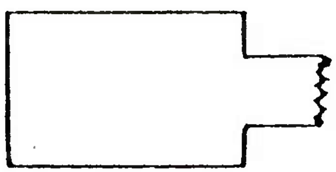
Most shields will easily provide this much attenuation without special precautions and without maintenance. The only EMP requirement is that materials must be specified and installation techniques documented to achieve the desired goal. Essentially, a high level of shielding effectiveness is not essential just a selection of the lowest cost technique.

Figure 2 illustrates the reduction in EMP induced current on a cable located various distances above a ground plane for various EMP rise times. It can be seen from the figure that for any specified height, an increase in rise time by an order of magnitude causes an order of magnitude reduction in the EMP current on the cable. Therefore if the shielding is used to increase rise time by a factor of 1000 and the cables laid on a ground plane then EMP currents are reduced by about 100 db.

TABLE 3. SHIELDED ENCLOSURE STANDARDS PROGRAM

Projects	Data Required for Standards
Shielding Specification Standards	1. Specification of shielding effectiveness necessary to reduce EMP energy damage levels on standard loops to less than 100 ujoules. 2. Specification of materials and installation techniques for various shielding methods.
Standards for Shielding Apertures, Cables and Cable Ducts	1. Parametric functions of aperture size versus EMP energy damage levels of 100 ujoule as a function of equipment or cable distance from the aperture. Specification of cable shielding and cable ducts to limit EMP energy to 100 ujoules. 2. Specification of materials and installation techniques.
Standards for Exterior and Interior Grounding of Shielded Enclosures Including Cables and Cable Ducts	1. Effectiveness of single and multiple ground schemes. 2. Requirements for interior cable shields and shield grounds at and between equipments.

TABLE 4

$.1M^2$  *100 OHMS	NO SHIELD	E = 277 uJ e = 167 VOLTS	FAIL
	20DB SHIELDS	E = 2.7 uJ e = .167 VOLTS	SAFE
$10M^2$  *100	NO SHIELD	E = 277 10^4 uJ e = 16,700 VOLTS	FAIL
	40DB SHIELD	E = 277 uJ e = 1.67 VOLTS	PASS

*100 OHMS TRANSISTOR AVALANCHE RESISTANCE AT ABOUT 30 VOLTS INDUCTANCE IS NEGLIBLE AND RESULTS CONSERVATIVE.

- ENERGY IN JOULES $= \dfrac{A^2 H^2 U_o^{\;2}}{t_r R}$

  e IN VOLTS $= \dot{\phi} = \dfrac{AB_{max}}{t_r}$

$$\left\{\begin{array}{l} H = \text{Magnetic Field} \\ t_r = \text{Rise Time} \\ A = \text{Loop Area} \\ U_o = 4\pi 10^{-7} \\ R = \text{Loop Terminating Res.} \\ B_{max} = U_o H_{max} \end{array}\right.$$

Figure 1

CABLE CURRENT VS HEIGHT ABOVE GROUND PLANE

FOR ELECTRIC FIELD RISE TIMES

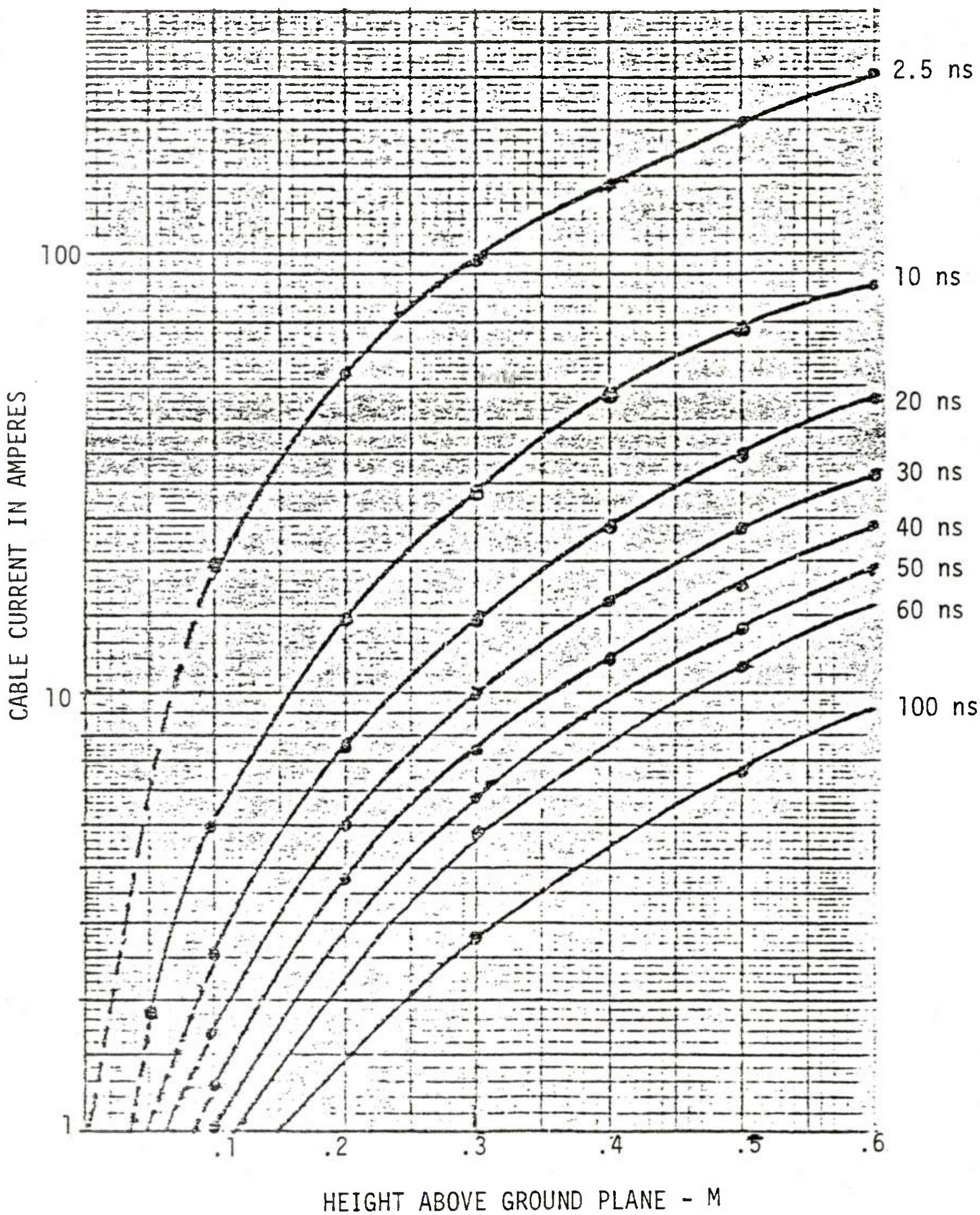


Figure 2

2.2.3 Relationship to Penetrator and Equipment Test Specification Standards

2.2.3.1 Penetrator standards are essential for effective shielded enclosure designs for buildings, rooms, and cable ducts to prevent the entry of high level EMP currents into the enclosure. Thus the two standards must be used together to avoid compromise of the design. The relationship between the two standards must be based on the relative amplitude and time relationship between the EMP energy delivered by the penetrators to the interior wiring and that received by diffusion through the shields. The shielding standard is tentatively set such that the diffusion energy will not exceed 100 ujoules (about a 2 Ap-p EMP current). The penetrator effectiveness must be adjusted by improving the techniques or the addition of protective devices until the same reduced energy level or better is achieved. Once the maximum penetrator effectiveness is achieved, the shielding requirements (usually superior in effectiveness to that of the penetrators) can be reduced accordingly if necessary to maintain consistency. The excess EMP energy above 100 ujoules that cannot be reduced by these two standards must then become a specification for a equipment testing standard. In other words, the equipment test specifications will not be necessary if the first two standards are effective in reducing the EMP energy below 100 ujoules.

2.2.4 Technical Problems Limiting Standards Development

There are no significant problems that limit standards development. In general it is necessary only to define the shielding enclosure effectiveness specification based on an arbitrarily selected EMP energy level induced in a standard loop size. It is also necessary to create several criteria on the allowable separation distances between apertures and equipment/cables and shield walls. Lastly, grounding standards for the enclosures and apertures must be defined such that the allowable single point and multiple point grounding variations are included in the standard.

2.3 Equipment Test Specification Standards

Equipment used in telecommunication facilities have a great variety of purposes such as power conversion, signal processing, transmitting and receiving. Functionally, any given equipment may be connected in some manner to many different facility penetrators such as AC Power lines, signal cables and control lines as well as being connected to other equipment within the facility. The EMP energy on penetrators and that on cabling isolated from penetrators is vastly different in magnitude and it is essential to rely on penetrator standards to force the two EMP energies to be no greater than 100 ujoules for the shielded case and 10 millijoules for the unshielded case. The approach tentatively adopted for this program is that equipment designed exclusively for operation from AC power have a unique test specification for the unshielded situation while for the shielded case all equipment will have a common test specification independent of whether it has a penetrator or inter equipment connection.

2.3.1 Purpose and Scope

The purpose of the program is to develop two EMP test specifications that define a pass-fail criteria for two classes of equipment. The program scope includes the definition of the test method, the test equipment required, test conditions, and a description of the waveform parameters. In practice it is intended that the EMP test waveform be applied to each external pin or connection on every equipment within the telecommunication facility. The test is envisioned as being performed at the factory or manufacturing facility on random equipment samples from the assembly line.

2.3.2 Test Specification for Communication and Control Equipment

2.3.2.1 Initial Criteria

The test specification for telecommunication equipment housed in shielded buildings or enclosures will require that equipments not be damaged at EMP energies above 100 ujoules while the energy criteria for the unshielded case has been established at 10 millijoules. The test specification criteria, as previously mentioned, is intended to be a pass-fail criteria that applies to each equipment within the facility with the exception of equipment connected to the AC power mains that is housed in unshielded buildings using overhead power lines.

2.3.2.2 Limitations

A final determination of the required specification for equipment requires that the energy difference between 100 ujoules and the penetrator leakage energy be known as well as the energy difference between the unshielded and shielded building cases. These two energy differences must then be summed to arrive at the final equipment test specifications. Therefore this specification cannot be completed until the two prior standards effectiveness has been established.

The unshielded building situation is a more complex specification than the shielded case for three reasons. The first reason is that the totality of the facility is exposed to the fast rise time of the EMP which causes very high voltages to develop on short lead lengths. Secondly, the EMP currents induced in the equipment ground returns and equipment racks are usually in excess of 100 Ap-p and produce voltages above 1000 volts between the signal/power lines and ground and lastly, the average energy exceeds 100 uj for most interrack wiring. These differential/common mode voltages plus the high voltages on relatively short ground buses or signal wires and the average energy for all cables cannot be determined in closed analytical form. The only choice under these conditions is a specification based on experimental evidence structured into statistical form to provide a distribution of probable EMP values for energy, voltage and current. The available data suggests that a 90% confidence can be obtained if equipment terminals are tested at about 1000 volts using the sine wave equivalents to the actual EMP waveforms. This type of specification relies on a small sample of equipment measurements and is somewhat suspect for that reason. It is economically unsound to accumulate sufficient data to satisfy the statistics therefore a second approach seems prudent. This choice involves the mandatory

use of metal cable ducts for enclosing all facility equipment wiring. These ducts for example, could be located in floor wells or above the equipment racks. In essence, this alternate choice is the equivalent of collapsing the overall building shield down to an enclosure shield that just surrounds the wiring.

It is not known whether or not building shielding plus penetrator isolation is effective enough to eliminate the requirement for equipment testing. Engineering judgment dictates that this is the case but from a standards viewpoint it appears useful to develop a two tier specification, one at the 100 uj level and one at the 10 mj level. By necessity, this latter criteria adds the complication of statistical uncertainty plus a stress test on equipment that is several orders of magnitude greater than the shielded case. The value of this approach remains to be seen. Conceptually, the cable duct (collapsed building shield) system is identical to the 100 uj level and its value as a base line standard requires exploration to assure that equipment connected in this manner does not require a third level test criteria.

2.3.2 Test Specification for AC Power Line Equipment

This standard will provide a test specification and requirement for telecommunication equipment connected directly to AC power lines that exit the facility. It applies only to those equipments that contain electronic components such as transistors, silicon controlled rectifiers, diodes or other solid state components. Typical equipment might include battery chargers, standby generator control systems and standby AC power systems that might contain sensors connected directly to the power mains.

The test specification criteria will be pass-fail as before and require the application of a unique test waveform of current or voltage of specified energy content to each pin or terminal of the equipment that connects to or is intended to be connected to the AC power mains.

This project must overcome a number of data deficiences before a standard can be postulated and finalized. Initially what must be determined is the degree of effectiveness that AC power line penetration standards can provide in reducing the EMP energy from overhead power lines and secondary EMP coupling sources. Secondary sources include such items as parking lot lights which are fed from interior facility power panels, power line neutrals and grounds, power lines from roof mounted air conditioners and exhaust fans. These secondary power lines pick up EMP energy and this energy adds to that from the main power cables feeding AC powered equipment. These various potentially additive EMP sources complicate the AC power specification process considerably. A two level specification may be necessary as described above, one for the unshielded building case and one for the shielded case.

2.4 Specifications Data Acquisition Plan Standards

The development of high confidence for EMP protection of telecommunication facilities cannot be achieved without acquiring additional data that can convincingly bound the upper limits to be expected from the EMP transient. These upper limits for equipment transient endurance requirements

are a direct function of the facility penetrator's ability to reduce or bound the EMP energy, voltage and current to predetermined limits. This interrelationship between penetrator standards, equipment endurance requirements and effectiveness of building, room or equipment shielding must be specified as a group relationship. In order to do this a systematic procedure and plan must be adopted to assure the development of a consistent set of standards.

A prudent plan is to construct a scale model shielded building with a number of penetrators including power lines, signal lines and grounding systems all appropriately terminated with suitable impedances. The first stage of the plan should be to determine the effectiveness and practicality of penetration treatments such that a few of these may be standardized and reduced to engineering practice. If this process is successful, then the second stage of experimentation may be initiated. This second stage would involve the development of test methods, test equipment and the specification of test waveshapes, and source impedance to be used in testing each equipment.

The final element of the plan is the documentation of the necessary standards and obtaining agreement from various standards groups within industry. Draft outlines and a few preliminary specifications for each of the three standards proposed are included in appendix A1, A2 and A3 and may be used to develop an overall plan.

2.5 Conclusions and Recommendations

The principal conclusions of this report are:

(1) The standards required to adequately specify techniques for portection of telecommunication facilities from disabling damage by HEMP are (a) standards for electrical isolation of EMP energy from facility penetrators (b) standards for electrical shielding of the facility (c) standards for EMP protection of equipment within the facility.

(2) Successful development of complementary "facility penetrator" and "facility shielding" standards with adequate HEMP attenuation requirements (30-40 db) should negate the requirement for any standards for HEMP protection of individual pieces of equipment within the facility.

(3) The standard with the greatest potential payoff in terms of reduction of HEMP vulnerability per dollar expended, and in terms of application to existing as well as future facilities is the "facility penetrator" standard. However, the initiation and successful completion of a study project to obtain answers to certain technical uncertainties associated with candidate HEMP protective devices is a prerequisite to any substantive work on this standard.

(4) The "facility shielding" standard is the standard which would require the least development time. When coupled with a complementary "facility penetrator" standard it would also provide the highest confidence level of EMP protection. There are no uncertainties which would preclude immediate initiation of a project to develop the "facility shielding" standard. However, its practical application would, until completion of the

complementary "facility penetrator" standard, be limited to those telecommunication facilities having no substantial number of penetrators (e.g., microwave repeater stations, etc.).

The recommendations are:

(1) A project plan should be developed for a study project to acquire the additional information required for the development of the "facility penetrator" HEMP protection standard and to explicitly define the complementary aspects of the "facility penetrator" and "facility shielding" standards. This project plan must also include a requirement for the development of test techniques for verifying the effectiveness of the protection techniques to be called out in both the "facility penetrator" and "facility shielding" standards.

(2) A standards development project should be initiated to develop the "facility shielding" standard in parallel with the above mentioned study project.

Appendix A1

Penetration Isolation Standard (Draft Outline)

1.0 Purpose

2.0 Scope

3.0 Entry Panel and Protection Device Standards

- 3.1 Entry Panel Design Criteria
- 3.2 EMP Arrestor Specifications
- 3.3 Filter Specifications
- 3.4 Arrestor and Filter Installation Criteria
- 3.5 Test/Inspection Methods
  - 3.5.1 Test Equipment
  - 3.5.2 Test Methods
  - 3.5.3 Test Specifications

4.0 Shielding and Grounding Standards

- 4.1 Entry Panel Grounding Methods
  - 4.1.1 Ground Rod Systems
  - 4.1.2 Ground Plane Systems
  - 4.1.3 Shielded Building
- 4.2 Penetrator Shielding/Grounding
  - 4.2.1 Signal Cable Shield Requirements
  - 4.2.2 Power Conduit Shield Requirements
  - 4.2.3 Non Electrical Penetrator Grounding

Preliminary Penetrator Isolation Requirements

Specification: Each facility penetrator will be capable of providing isolation/reduction of EMP currents of greater than 30 db. The protective devices, if any, shall be fail safe and capable of handling surge voltages up to 10 kv and surge currents up to 5 ka for 5 usecs or greater.

EMP surge arrestors must operate in less than 50 nanoseconds while maintaining the required isolation and perform without degradation when operated in parallel with standard lightning discharge devices.

Penetrators: Facility penetrators must be placed below ground buried to a practical depth to prevent damage by vehicular traffic with any conductors enclosed in standard steel conduit which extends beyond the building entry plate by a distance of 10 meters minimum.

Appendix A2

Building Shielding Standard (Draft Outline)

1.0 Purpose

2.0 Scope

3.0 Shielding Effectiveness Criteria

- 3.1 Buildings
- 3.2 Rooms
- 3.3 Cable Ducts
- 3.4 Apertures (Doors and Windows)

4.0 Shielded Enclosure Grounding Requirements

- 4.1 Interior Equipment Grounds to Shields
- 4.2 Exterior Grounds to Shields

5.0 Shield and Equipment Standards

- 5.1 Separation Distances from Apertures
- 5.2 Shield to Equipment Separation Distances

6.0 Test Methods

- 6.1 Test Equipment
- 6.2 Test Methods
- 6.3 Test Specifications

7.0 Visual Inspection Criteria

Preliminary Building Shielding Specification

Specification: The building shield will provide a minimum of 30 db of peak magnetic field shielding effectiveness from 10KHz to 10 MHz at a distance of 1 meter from any shield surface. The energy induced in a standard loop shall be no greater than 100 ujoules for any orientation.

Apertures such as doors and windows shall be equipped with wire mesh or the equivalent to provide 30 db attenuation from 10KHz to 10MHz at a distance of twice the largest dimension of the aperture.

Shield grounds whether exterior or interior to the shield shall not penetrate the shield material.

Appendix A3

Equipment Test Specification Standard (Draft Outline)

1.0 Purpose

2.0 Scope

3.0 Test Specification for Equipment in Shielded Enclosures

4.0 Test Specification for Equipment in Unshielded Enclosures

5.0 Test Specification for Equipment Connected to AC Power Mains

- 5.1 Overhead Cables
- 5.2 Buried Cables

6.0 Test/Inspection

- 6.1 Test Equipment
- 6.2 Test Methods

Preliminary Equipment Test Specification

Specification: Equipment located in unshielded enclosures shall be tested by applying a test pulse of 1KV that has a rise time of 30 nanoseconds and a duration of 10 useconds. The test pulse will be applied to each equipment terminal and ground and between each balanced pair, if any. The test pulse source impedance will be 50 ohms.

BIBLIOGRAPHY

1. Final Report, Effects of EMP on Bell System Long Haul Transmission Facilities, April 1974, Bell Laboratories, Contract DAHC60-70-C-0071 (Unclassified).

2. Final Report, Safeguard Communications Agency EMP Effects Analysis and Test Program (U), MITRE Corp., M74-220, August 1974 (Secret).

3. DCPA Report TR 61, "EMP Threat and Protective Measures", August 1970.

4. DCPA Report TR 61A, "EMP Protection for Emergency Operating Centers", July 1972.

5. DCPA Report TR 61B, "EMP Protective Systems", July 1976.

6. DCPA Report TR 61C, "EMP Protection for AM Radio Broadcast Stations", July 1976.

7. DCPA Report 61D, "EMP and Electric Power Systems", July 1973.